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Mechanical Response of Future Combat Systems (FCS) High-Energy Gun Propellants at High-Strain Rate

by Michael G. Leadore

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Mechanical Response of Future Combat Systems (FCS) High-Energy Gun Propellants at High-Strain Rate

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Abstract

Five lots of Future Combat Systems high-energy gun propellants were tested in uniaxial compression at high-strain rate. A production lot of JA2 that is currently used in the M865 round was also tested for comparison purposes. The materials were tested for comparison purposes. The materials were tested while conditioned at temperatures of 21°, 63°, and –32 °C. The materials were taken to ~60% strain using a deformation rate of 1.3 m/s. The stress at failure, strain at failure, compressive modulus, failure modulus, incremental energy density, and the fracture assessment values were recorded for each test.

Contents

List of Figures v

List of Tables vii

1. Introduction 1

2. Background 1

3. Approach and Results 2

4. Conclusions 2

5. References 7

Distribution List 9

Report Documentation Page 25

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List of Figures

Figure 1. Prepared test specimen being loaded for compression test. 1

Figure 2. Stress vs. strain plot of JA2 and Thiokol propellants tested at 21 °C. 4

Figure 3. Tested remains of JA2 lot HCL93J014-001. 5

Figure 4. Tested remains of Thiokol lots at 21°, 63°, and –32 °C. 5

Figure 5. Stress vs. strain plot of JA2 and Thiokol propellants tested at 63 °C. 6

Figure 6. Stress vs. strain plot of JA2 and Thiokol lots at –32 °C. 6

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List of Tables

Table 1. Mechanical properties of Thiokol and JA2 lots at 21 °C............................ 3

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1. Introduction

The following is the U.S. Army Research Laboratory's (ARL's) report of the material test systems (MTS) servo-hydraulic tester (SHT) high-rate mechanical response of Thiokol lots TGD-022, TGD-023, TGD-024, TGD-025, and TGD-022/023/022 layered (five lots) (test sets 07–21 Fiscal 02). The Thiokol materials are candidate gun propellants for the Future Combat System (FCS). A production lot of JA2 lot no. HCL93J014-001 was also tested using identical test conditions for comparative purposes.

2. Background

Five lots of Thiokol gun propellants were received from Joseph Colburn of ARL. The Thiokol lots were extruded into a solid-sheet configuration and shipped to ARL's Dr. Robert Lieb. Also, a production lot of JA2 granular propellant was procured from Aberdeen Proving Ground (APG) for comparison testing. All of these materials were tested during October 2001 for high-rate uniaxial compression mechanical response evaluation (Figure 1).

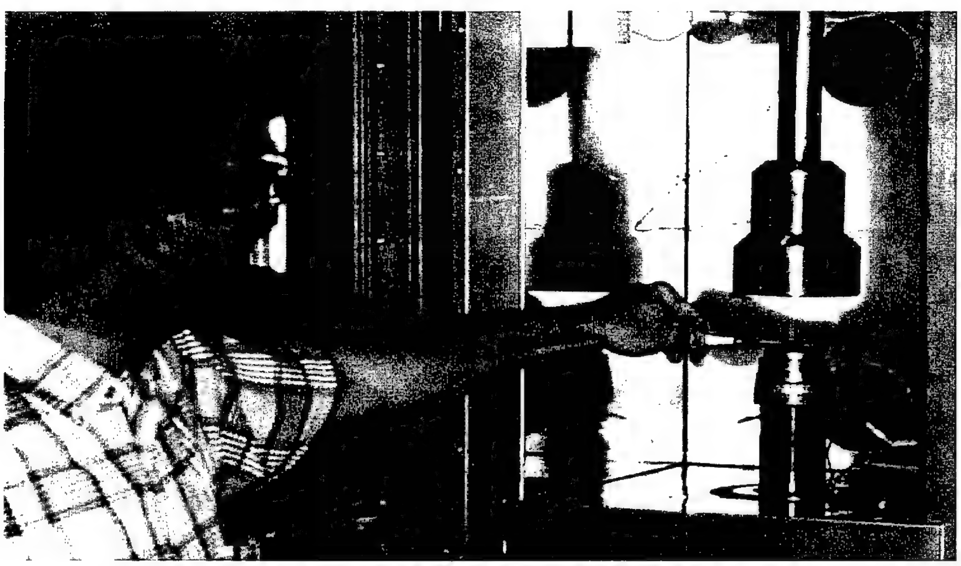

Figure 1. Prepared test specimen being loaded for compression test.

3. Approach and Results

The Thiokol lots were received in solid-sheet form. The JA2 lot was granular with a diameter of 9.80 mm and was cut using a double-bladed diamond saw. Sample ends were machined so that the surfaces were flat, parallel to each other, and perpendicular to the extruded axis. The Thiokol lots were punched out using a 12.7-mm stainless steel hole punch. The punched samples were then stacked to make a test specimen.

MTS SHT mechanical properties tests (1–7) were conducted on several specimens under each test condition. Strain rates of 133.0 s^{-1} were achieved. The specimens were taken to failure at ambient pressure to ~50% end strain while conditioned at temperatures of 21°, 63°, and –32°C. The stress at failure, strain at failure, the modulus, failure modulus, the incremental energy density, and the fracture assessment value were recorded for each test (Table 1).

4. Conclusions

Five lots of Thiokol high-energy gun propellants and a production lot of JA2 were tested for mechanical response evaluation at ambient pressure while conditioned at 21°, 63°, and –32 °C. The materials were tested in uniaxial compression to ~50% end strain using a deformation rate of 1.35 m/s.

At 21 °C, the Thiokol lots and the JA2 lot all showed good response to high-rate uniaxial compression. Note the compressive modulus values for the Thiokol lots are ~50% less than the JA2 production lot. The positive failure modulus values achieved indicated all of the lots' abilities to sustain load beyond ~50% strain. Note the stress vs. strain plot (Figure 2) shows the JA2 lot workhardening beyond 50% strain. The tested specimens (Figures 3 and 4) suffered permanent deformation with very minimal fracturing.

At 63 °C, again, the mechanical response of all the lots was quite good. The Young's modulus values showed some "softening" as a result of the higher testing temperature, as expected. The stress/strain plot (Figure 5) shows all the lots able at sustaining load. The tested specimens again showed very minimal axial fracture and deformation (Figures 3 and 4).

Table 1. Mechanical properties of Thiokol and JA2 lots at 21 °C.

Lot	Stress at Failure (MPa)	Strain at Failure (%)	Modulus (GPa)	Failure Modulus[a] (GPa)	IED[b] (MPa)	FAV[c] (MPa)
at 21 °C						
Thiokol Lot TGD-022	42.01	19.04	0.341	0.0980	7.19	1AB
Thiokol Lot TGD-023	36.19	16.51	0.283	0.0424	6.63	1AB
Thiokol Lot TGD-024	33.63	19.21	0.218	0.0564	5.38	1AB
Thiokol Lot TGD-025	40.19	15.31	0.355	0.0299	7.75	1AB
Thiokol Layered TGD-022/023/022	33.00	16.24	0.260	0.0590	6.42	1AB
JA2 Lot HCL93J014001	16.87	4.56	0.722	0.0523	5.37	1B
at 63 °C						
Thiokol Lot TGD-022	16.33	15.11	0.110	0.0623	3.22	0B
Thiokol Lot TGD-023	12.59	15.14	0.088	0.0561	2.49	0B
Thiokol Lot TGD-024	12.65	18.23	0.072	0.0522	2.07	0B
Thiokol Lot TGD-025	18.55	15.22	0.140	0.0311	3.41	0B
Thiokol Layered TGD-022/023/022	15.03	19.13	0.075	0.0511	2.44	0B
JA2 Lot HCL93J014001	8.86	4.59	0.244	0.0290	2.57	1B
at –32 °C						
Thiokol Lot TGD-022	74.08	8.07	1.94	–0.0053	16.25	4AS
Thiokol Lot TGD-023	78.23	7.85	1.59	–1.070	11.70	6AS
Thiokol Lot TGD-024	86.11	7.65	2.11	–0.250	16.62	6AS
Thiokol Lot TGD-025	108.07	6.50	3.77	–0.677	16.48	7AS
Thiokol Layered TGD-022/023/022	76.08	7.88	1.61	–1.070	8.81	8AS
JA2 Lot HCL93J014001	54.03	7.09	1.62	0.067	13.82	5AS

[a]The failure modulus (slope of the curve after failure) has been added. Generally, the lower the value, the worse the material (i.e., a negative value indicates the material is unable to sustain load). A positive value indicates a positive failure slope (i.e., the material is better able to support load after failure).

[b]The incremental energy density (IED) value reported is the amount of energy per unit volume absorbed at 25% strain; this includes a portion of the area located beneath the stress/strain curve.

[c]The tested specimens were assigned a fracture assessment value (FAV). The values range from 0 (no observed fracturing) through 9 (severe fracturing observed). The type of fracture was also characterized using the following methodology: A = axial fracture, S = shear fracture, B = barreling/deformation, R = radial splitting (i.e., 9A indicates the tested specimens showed a severe amount of axial fracture).

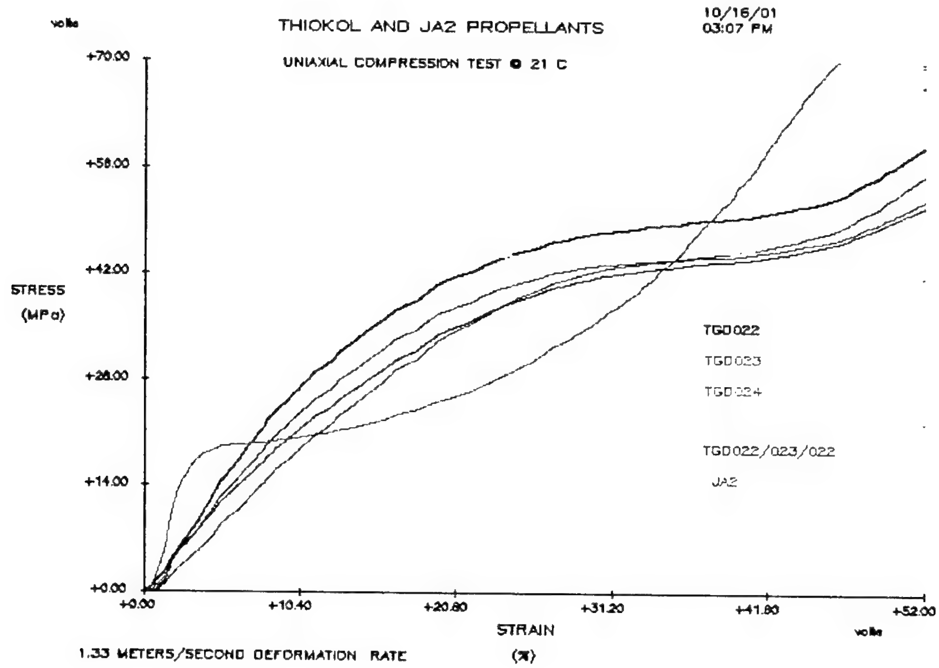

Figure 2. Stress vs. strain plot of JA2 and Thiokol propellants tested at 21 °C.

At –32 °C, the tested specimens (Figures 3 and 4) suffered moderate amounts of axial and shear fracture. Note the stress/strain plot at –32 °C (Figure 6) shows the JA2 lot able at sustaining load and workhardening up to 50% strain and thus, the only lot yielding a positive failure modulus value. Lot TGD-022 provided the better mechanical response compared to the remaining Thiokol lots. Lot TGD-022 also was able to sustain load at –32 °C. The layered lot TGD-022/023/022 yielded values similar to lot TGD-023. This was expected as lot TGD-023 showed a poor response to mechanical testing, and the layered lot was comprised of lots TGD-022 and TGD-023. The modulus value for lot TGD-025 was alarmingly high, indicating possible sensitivity to –32 °C.

Overall, all of the materials' mechanical responses at 21° and 63 °C were very good. At –32 °C, the JA2 lot was clearly the better material, followed by lot TGD-022. The layered lot TGD-022/023/022 suffered much fracture at –32 °C, but did not show any separation between the layers.

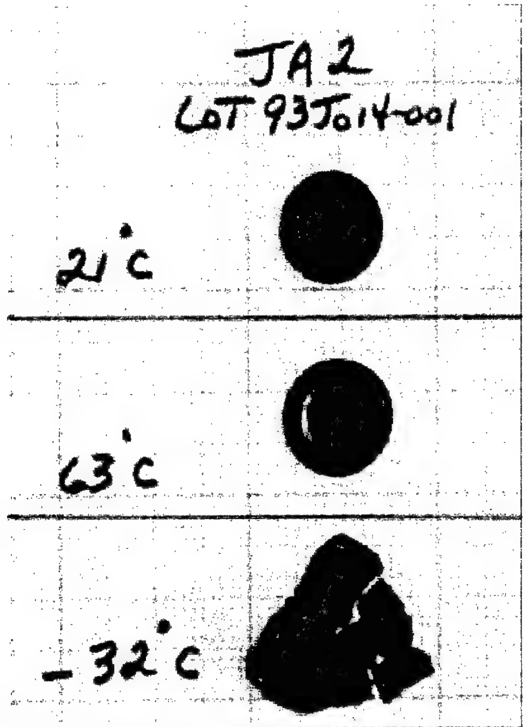

Figure 3. Tested remains of JA2 lot HCL93J014-001.

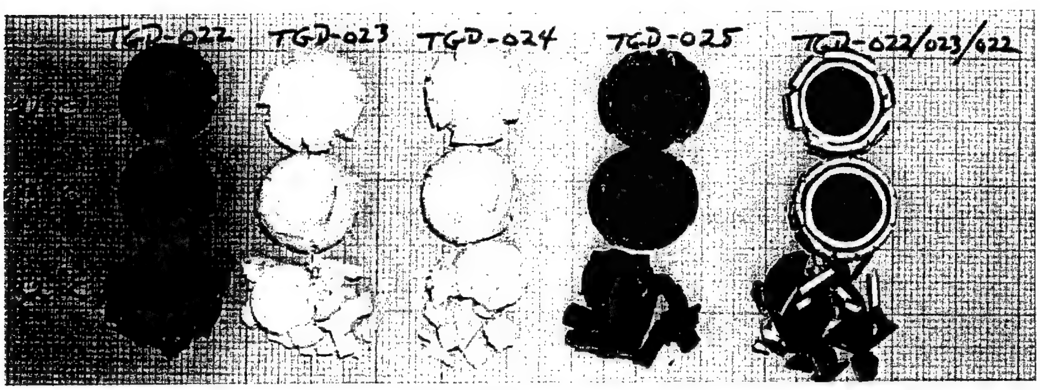

Figure 4. Tested remains of Thiokol lots at 21°, 63°, and –32 °C.

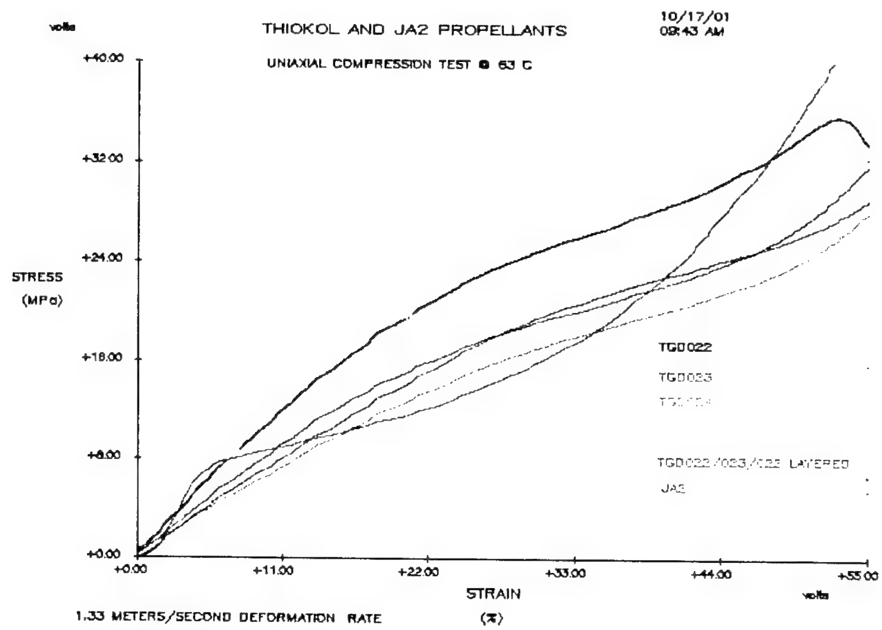

Figure 5. Stress vs. strain plot of JA2 and Thiokol propellants tested at 63 °C.

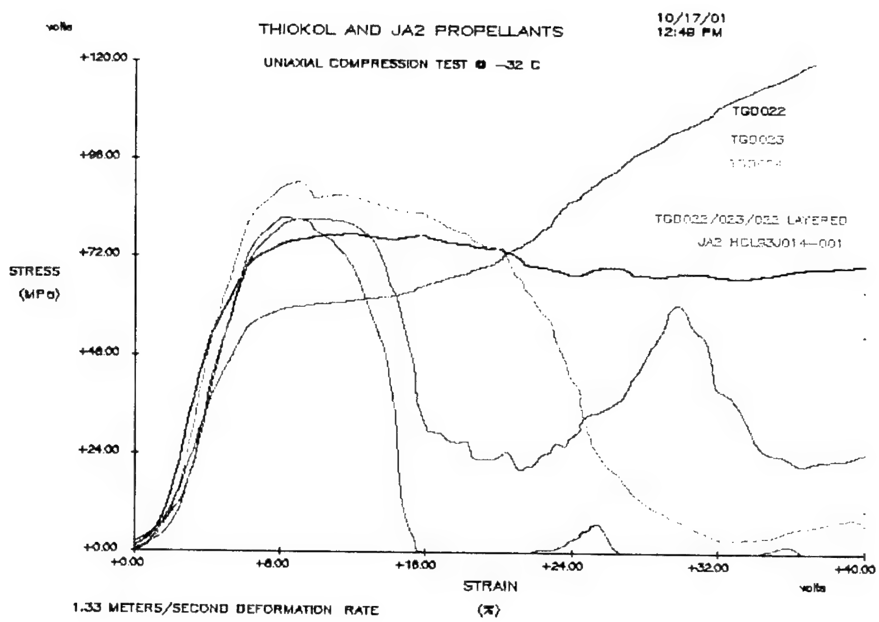

Figure 6. Stress vs. strain plot of JA2 and Thiokol lots at -32 °C.

5. References

1. Gazonas, G. A. "The Mechanical Response of M30, XM39, and JA2 Propellants at Strain Rates From 10-2 to 250 Sec-1." BRL-TR-3181, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, January 1991.

2. Lieb, R. J. "Impact-Generated Surface Area in Gun Propellant." BRL-TR-2946, U.S. Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD, November 1988.

3. Lieb, R. J., and J. J. Rocchio. "High Strain Rate Mechanical Properties Testing on Lots of Solid Gun Propellant With Deviant Interior Ballistic Performance." *1982 JANNAF Structures and Mechanical Behavior Subcommittee Meeting*, CPIA Publication 368, pp. 23–38, October 1982.

4. Leadore, M. G. "MTS Servo-Hydraulic Tester (SHT) Mechanical Properties Evaluation of M43 Propellants." ARL-TN-5, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, March 1993.

5. Leadore, M. G., and C. J. Gillich. "Material Testing System (MTS) Servo-Hydraulic Tester (SHT) Mechanical Response of Energetic Thermal Plastic Elastomer (ETPE) RDX-Based Propellants." ARL-TN-28, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, April 1994.

6. Leadore, M. G. "Mechanical Response of Energetic Thermoplastic Elastomer Low-Vulnerability Ammunition (ETPE-LOVA) RDX-Based, TNAZ-Based, and CL-20-Based Gun Propellants." ARL-TN-64, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, March 1996.

7. Lieb, R. J. Personal communication. U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, October 2001.

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13. ABSTRACT *(Maximum 200 words)*

Five lots of Future Combat Systems high-energy gun propellants were tested in uniaxial compression at high-strain rate. A production lot of JA2 that is currently used in the M865 round was also tested for comparison purposes. The materials were tested for comparison purposes. The materials were tested while conditioned at temperatures of 21°, 63°, and –32 °C. The materials were taken to ~60% strain using a deformation rate of 1.3 m/s. The stress at failure, strain at failure, compressive modulus, failure modulus, incremental energy density, and the fracture assessment values were recorded for each test.

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